U. S. Forest Service
Research Paper RM-21
1966

YIELD TABLES FOR MANAGED STANDS

With Special Reference To The Black Hills

by

Clifford A. Myers

Rocky Mountain Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture

U. S. Forest Service Research Paper RM-21 1966

YIELD TABLES FOR MANAGED STANDS WITH SPECIAL REFERENCE TO THE BLACK HILLS

by

Clifford A. Myers, Principal Mensurationist

Rocky Mountain Forest and Range Experiment Station[1]

[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins,

Contents

Yield Tables for Managed Stands with Special Reference to the Black Hills

by

Clifford A. Myers

Yield tables that show, or are convertible to show, potential production in even-aged managed stands are becoming ever more necessary in the United States. Many forests are already fully managed and can benefit from refinements in operations that are guided by comparison of actual conditions with a good standard. Vast areas are being converted from virgin forests to managed stands. Yield tables that show what can be accomplished by good management practices provide goals toward which conversion can be directed. Unfortunately, useful tables are not generally available for American species and forest regions.

Normal yield tables, the type usually available, are based on a concept that is invalid in many areas. Stand densities defined as "normal" may actually represent severe overstocking. This is the case with interior ponderosa pine, where full stocking is better indicated by root closure than by space occupied by tree crowns. "Normal" stocking is so often in excess of that necessary to meet management goals that recommendations have frequently been made to accept 50 to 70 percent of yield table values as standard. Such recommendations are of limited value where "normal" stocking represents slow growth or stagnation, and thus implies abnormal relationships between tree diameter, height, and age. How is an adjustment to 50 percent of normal yield table values to be interpreted, where 50 percent of normal basal area can produce 200 percent of normal merchantable volume? Unless adjustment procedures can successfully cope with such situations, normal yield tables cannot be used to predict production in managed stands.

Empirical yield tables, based on normal yield table procedures except for the concept of normality, may not be an improvement over normal yield tables. Stand densities sampled may be far from management objectives where uncut or conservatively cut stands are numerous.

A more reasonable approach is to observe carefully thinned and measured plots for one or more cutting cycles. A limited series of plots will provide data for experience yield tables that describe response to certain management procedures. Data from a larger series that samples across the ranges of important stand variables can be analyzed by multiple regression methods and summarized in variable-density yield tables.

Yield plots tie up much of the limited supply of research time and money, and provide answers slowly. Research resources may be sufficient to cope with plot installation and measurement now for only one or two important species or types in each forest region. It is unreasonable to expect demands for information to be met in such fashion simultaneously for all forest types or species.

Yield tables for managed stands can be prepared quickly and inexpensively from data collected on temporary plots. Procedures for doing this for pure, even-aged stands are presented here as a series of steps that describe field and office operations. The method provides current answers to current demands for information. For many species, such work could be the only type of yield study possible for many years.

General Description of Method

Most forest regions contain stands that have been thinned one or more times to densities near desirable management levels. These stands provide a readily available store of growth information. They also provide a basis for good estimates of desirable stocking levels for managed stands. The method described here makes use of such stands and published and unpublished information to obtain estimates of yields in managed stands that do not yet exist.

Ten items of information are needed to prepare yield tables for even-aged managed stands. Two items are determined initially; they summarize management goals for the species and guide field sampling. The other eight items can be obtained from available information and a season's field work if such tools as volume tables and site index curves are already available.

Initial management decisions are as follows:

1. Description of young stands prior to initial thinning. This involves several management decisions, including the regeneration system used to create the young stands.
2. Estimates of stocking immediately after thinnings or other intermediate cuttings throughout a rotation. This is about equivalent to a thinning guide for well-managed stands.

The eight working tools to be developed from field data and available information are as follows:

1. Largest diameters in unthinned young stands in relation to average stand diameter.
2. Stand tables for unthinned young stands of known average stand diameter.
3. Equation for estimating the periodic increase in stand diameter for various combinations of stand density and site quality.
4. Increase in stand diameter solely as a result of thinning.
5. Equation for estimating the periodic increase in basal area for various combinations of stand density and site quality.
6. Average height of dominant and codominant trees in stands of various ages where height growth has not been reduced by high stand density.
7. A stand volume equation in cubic feet with independent variables available from the other listed items.
8. Factors to convert volumes per acre from cubic measure to other units.

Once the 10 items are available, yield tables are derived as a series of projections. Starting point of the projections is defined by the description of young, unthinned stands and management decisions related to them. Growth of the stands is estimated by the diameter growth equation, the height-age relationship, and the effect of thinning on average stand diameter. Reductions in stand density due to intermediate cutting are specified by the stocking standards to be followed as management goals.

Inclusion of management decisions in the procedure is unavoidable because the yield tables are for managed stands. With the methods described here, however, management decisions may be changed freely to match changes in product objectives or silvicultural goals. Most working tools that come from field data and represent the expenditure of time and money will not change. Anyone can use the working tools to prepare yield tables for managed stands that describe what will happen after application of his concept of good management.

Yield tables for managed stands of ponderosa pine (Pinus ponderosa Laws.) in the Black Hills of South Dakota and Wyoming were derived as an example of procedure. Management decisions on which the yield tables are based were determined by characteristics of Black Hills stands and probable future management goals. Foresters working in the Black Hills who do not agree with these decisions can easily substitute their own. Foresters interested in the method but not in Black Hills stands can follow the procedure, substituting decisions and data applicable to their area.

Initial Management Decisions

Two sets of decisions must be made before field work can be planned: (1) how stands are to be regenerated and the appearance of these stands early in a rotation, and (2) stocking to be maintained throughout a rotation to meet product and other objectives. Data on which to base these decisions are readily available where young even-aged stands exist, and where results of thinning studies are available or can be simulated by increment cores. Some data can be gathered on temporary plots; other data are in the literature. Because needs will vary locally, they are not discussed in the section

on field work. Decisions to be made and data needed to make them can be determined from the following sections.

Stands Prior to Thinning

Description of the early life of a stand includes:

1. Number of trees per acre at the earliest stand age to be considered in the yield tables. Regeneration system used to create the stand must be determined at this point.
2. Age when stands of this density will first need thinning.
3. Mortality in numbers of trees each 10 years, or other period, from the earliest age of interest to age at first thinning.
4. Average stand diameter at the end of each 10 years, or other period, from the earliest age of interest to age at first thinning.

Ways to obtain such descriptive material are illustrated by decisions made for ponderosa pine in the Black Hills.

1. Desirable number of trees per acre at age 10 was estimated to be about 2,000. Examination of numerous young stands of ponderosa pine in the Black Hills and in Arizona indicated that a moderate stand density will insure the formation of straight boles. High densities that lead to slow growth and stagnation (Myers 1958, Myers and Van Deusen 1960b) [2] and low densities that encourage the development of "apple trees" must be avoided.

   A stand of 2,000 seedlings per acre can be attained in the final steps of regeneration cutting by uniform shelterwood. The final cut will destroy some seedlings; undisturbed patches can be opened with brush axes or other tools that quickly lop trees not needed. Future research may reveal that desired density can be obtained by controlling the amount of shelterwood and the time it is removed. In any event, it is not necessary to save exactly 2,000 seedlings, or exactly any other number used as a guide.
2. Thinning will probably be unnecessary in stands less than 30 years old if density at age 10 is about 2,000 trees per acre. Desirable stand density (decision one, above) was determined first. Then, borings were made in dominant and codominant trees 10 to 50 years old to observe the effects of age and stand density on radial growth.
3. Examination of numerous unthinned young stands where mortality could be dated with reasonable accuracy indicated that 2,000 trees per acre would be reduced to about 1,850 after 10 years. No differences due to site quality could be found. Mortality estimates to age 30 varied with site quality, as shown in the yield tables (see tables 6-9).
4. Average stand diameter before initial thinning was determined from measurements of moderately stocked, unthinned stands 25 to 35 years old. Diameter and basal area growth equations applicable to unthinned stands were used to check the diameter-age relationships obtained (Myers and Van Deusen 1961).

[3] *Names and dates in parentheses refer to Literature Cited, p. 20.*

Stocking After Cutting

Stocking to be left after each intermediate cutting is an important management decision because of its effect on growth and yield. Reserve density will vary with age or diameter of the stand, site quality, and the objectives of management.

One way to choose stocking levels is illustrated by decisions made for Black Hills ponderosa pine. The decisions and reasons for them were as follows:

1. Stocking would be expressed by a relationship between basal area and average stand diameter. Basal area is an easily measured variable (Grosenbaugh 1952) that is highly correlated with growth in size and volume (Myers and Van Deusen 1961).
2. Basal area left after cutting would increase with stand diameter until a specified diameter was reached. Thereafter, equal basal areas would be left after each intermediate cutting. For the Black Hills, basal area would be held constant after stand diameter reached 10 inches.

3. Several basal area-diameter relationships would be equally acceptable as standard to provide for variation in management goals.
4. Age would not be used in the definition of stocking levels. Many stands had gone through periods of slow growth or suppression. Relationships between age and diameter or between age and merchantable volume were expected to be different under management.

Once these decisions had been made, published (Myers 1958) and unpublished results of thinning experiments dating back to 1909 were examined. For each stand diameter represented, the residual basal area tested that appeared best was determined. Major factors considered in the ratings were growth per acre in cubic volume to a 4-inch top, and probable length of saw log rotations. Site quality was ignored since most results were from areas of average site index.

Basal areas that appeared best were plotted over corresponding stand diameters, and a curve was drawn through the points. The points defined the curve so well that almost no balancing was necessary. This curve (level 80 of fig. 1) was accepted as the optimum growing stock for managed stands on areas of average site quality. Other curves were drawn at various percentages of basal area above and below the level 80 curve so that they passed through 50, 60, 70, etc. square feet at a d.b.h. of 10 inches. Form of the resultant curves of basal area on diameter (fig. 1) resembled curves of basal area on age for normal stands (Meyer 1938).

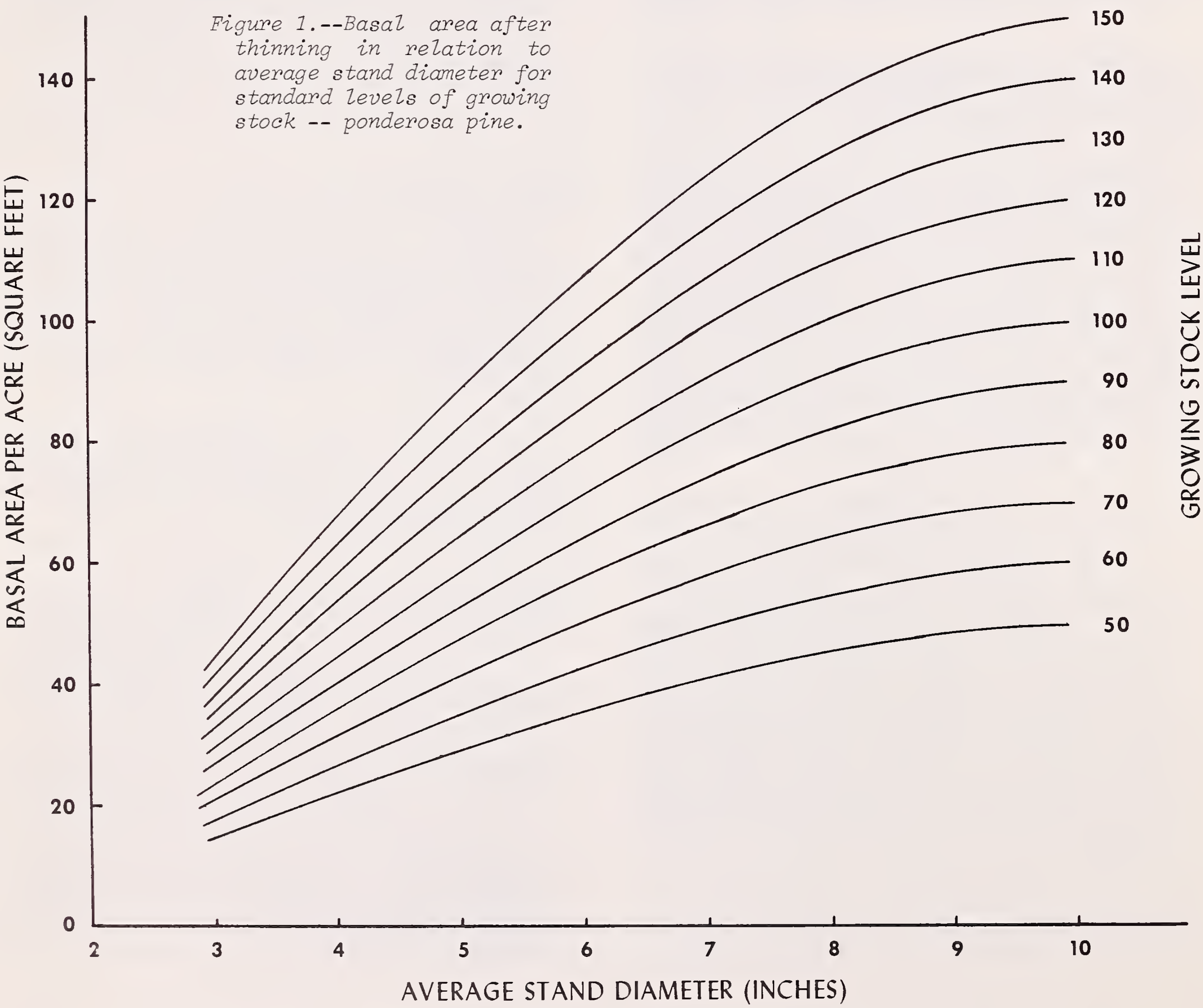


Figure 1.--Basal area after thinning in relation to average stand diameter for standard levels of growing stock -- ponderosa pine.

The curves define optimum growing stock for various management objectives, including the possibility of holding stand density above or below levels that give the best saw log and pulpwood production. Basal areas are readily converted to numbers of trees per acre (table 1) or to other guides for the conduct of actual thinning operations.

Specific stocking goals will hereafter be referred to as stocking level 80, stocking level 90, and so forth. A given level is defined by a curve of fig. 1, and is named by the basal area to which the stand is cut after diameter reaches 10 inches. A level is also described by the column of table 2 headed by the number that names the level.

Table 1. --Number of trees per acre after thinning, in relation to average stand diameter. Standard levels of growing stock for ponderosa pine in the Black Hills.

Average stand d.b.h. after thinning (Inches)	Growing stock level						
	60	70	80	90	100	110	120
				Number			
1.0	505	589	665	757	841	925	1,009
1.5	451	526	602	677	752	827	902
2.0	423	494	565	635	705	776	846
2.5	389	454	518	584	649	714	779
3.0	360	421	480	541	601	661	721
3.5	332	388	443	499	554	609	665
4.0	302	353	403	454	504	554	605
4.5	279	325	371	418	464	511	557
5.0	257	300	343	385	428	471	514
5.5	235	274	313	352	391	430	469
6.0	216	252	288	324	360	396	433
6.5	199	232	265	298	331	365	398
7.0	184	214	245	276	306	337	368
7.5	169	197	225	253	282	310	338
8.0	156	182	208	234	260	286	312
8.5	143	167	191	215	239	263	287
9.0	132	153	175	197	219	241	263
9.5	120	140	161	181	201	221	241
10.0	110	128	147	165	183	202	220
11.0	91	106	121	136	152	167	182
12.0	76	89	102	115	127	140	153
13.0	65	76	87	98	108	119	130
14.0	56	65	75	84	94	103	112
15.0	49	57	65	73	81	90	98
16.0	43	50	57	64	72	79	86
17.0	38	44	51	57	63	70	76
18.0	34	40	45	51	57	62	68
19.0	30	36	41	46	54	56	61
20.0	28	32	37	41	46	50	55

Table 2. --Growing stock levels for Black Hills ponderosa pine. Basal areas after intermediate cutting in relation to average stand diameter.

Average stand d.b.h. after cutting (Inches)	Growing stock level							
	50	60	70	80	90	100	110	120
				Square feet per acre				
2.0	7.7	9.2	10.8	12.3	13.8	15.4	16.9	18.4
2.2	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6
2.4	10.4	12.4	14.5	16.6	18.7	20.8	22.8	24.9
2.6	11.8	14.2	16.5	18.9	21.3	23.6	26.0	28.4
2.8	13.3	16.0	18.6	21.3	24.0	26.6	29.3	32.0
3.0	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4
3.2	16.2	19.5	22.8	26.0	29.2	32.5	35.8	39.0
3.4	17.8	21.3	24.8	28.4	32.0	35.5	39.0	42.6
3.6	19.2	23.0	26.9	30.7	34.5	38.4	42.2	46.0
3.8	20.6	24.7	28.8	32.9	37.0	41.1	45.2	49.4
4.0	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8
4.2	23.5	28.2	32.9	37.6	42.3	47.0	51.7	56.4
4.4	24.9	29.8	34.8	39.8	44.8	49.8	54.7	59.7
4.6	29.4	31.6	36.9	42.2	47.5	52.8	58.0	63.3
4.8	27.9	33.4	39.0	44.6	50.2	55.8	61.3	66.9
5.0	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0
5.2	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2
5.4	31.8	38.2	44.5	50.9	57.3	63.6	70.0	76.4
5.6	33.0	39.6	46.2	52.8	59.4	66.0	72.6	79.2
5.8	34.2	41.0	47.9	54.7	61.5	68.4	75.2	82.0
6.0	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9
6.2	36.6	43.9	51.2	58.5	65.8	73.1	80.4	87.8
6.4	37.7	45.2	52.8	60.3	67.8	75.4	82.9	90.4
6.6	38.8	46.5	54.2	62.0	69.8	77.5	85.2	93.0
6.8	39.9	47.8	55.8	63.8	71.8	79.8	87.7	95.7
7.0	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2
7.2	41.9	50.2	58.6	67.0	75.4	83.8	92.1	100.5
7.4	42.8	51.3	59.8	68.4	77.0	85.5	94.0	102.6
7.6	43.6	52.4	61.1	69.8	78.5	87.2	96.0	104.7
7.8	44.5	53.4	62.3	71.2	80.1	89.0	97.9	106.8
8.0	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8
8.2	46.1	55.4	64.6	73.8	83.0	92.2	101.5	110.7
8.4	46.8	56.2	65.5	74.9	84.3	93.6	103.0	112.4
8.6	47.4	56.8	66.3	75.8	85.3	94.8	104.2	113.7
8.8	47.9	57.5	67.1	76.7	86.3	95.9	105.5	115.0
9.0	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2
9.2	48.9	58.6	68.4	78.2	88.0	97.8	107.5	117.3
9.4	49.2	59.1	69.0	78.8	88.6	98.5	108.4	118.2
9.6	49.5	59.4	69.3	79.2	89.1	99.0	108.9	118.8
9.8	49.8	59.8	69.7	79.7	89.7	99.6	109.6	119.6
10.0+	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0

Development of Working Tools

Field Work

Data needed to construct the yield tables were obtained on temporary plots placed in carefully selected even-aged stands. Two

types of plot were measured. "Unthinned plots" were placed in unthinned, sapling, and small pole stands. "Growth-prediction plots" were located in thinned stands of all ages to about 40 years beyond estimated rotation age for saw logs. For the Black Hills, 43 unthinned plots and 95 growth-prediction plots were measured.

Unthinned plots were placed in even-aged stands about 30 years old with densities similar to those expected in stands described in "Stands Prior to Thinning." Densities somewhat heavier and lighter than expected were also sampled to determine the effect of variations in initial density. The measurements made on unthinned plots were: (1) plot area (at least 0.25 acre), (2) site index, and (3) diameter of each tree to 0.1 inch. These data were used to prepare stand tables for unthinned, young stands. Unthinned plots also provided information on diameter-age relationships in young stands (item 4 of "Stands Prior to Thinning").

Most data needed to prepare the working tools were obtained from growth-prediction plots. These plots conformed to the following standards:

1. Were uniform in site quality, range of tree sizes, and stand density on and adjacent to the plot.
2. Varied in area with average stand diameter. With small trees, the plots were at least large enough to contain 150 trees. In low-density or sawtimber stands, a practical minimum area was about 0.5 acre. It was rarely possible to exceed minimum area in the Black Hills because of frequent changes in stand condition and site quality.
3. Supported even-aged, thinned stands that had not been cut or otherwise disturbed within 13 years prior to measurement. The 3 years beyond the 10-year measurement period was to allow for severe adjustments in form that would not be expected in continually managed stands of low density.
4. Did not have disease or insect damage that affected growth. It was necessary, however, to sample a few stands with small amounts of western gall rust (Cronartium harknessii Moore Ex Hark) so that a wide range of stand diameters and densities would be measured.
5. Had stand diameters reasonably close to those possible in managed stands of equal age. Some leeway was found to be allowable in this standard, but all extreme conditions were rejected.

An additional restriction was placed on the stand densities sampled: Only plots with growing stock levels within a predetermined range 10 years prior to measurement were accepted in the final sample. It was decided that levels 80 and 100 (table 2) would describe the most important alternatives of management for the Black Hills. Plots with past stocking levels of 50 to 170 were therefore selected to sample conditions of interest, provide for possible variation in management goals, and measure a range of conditions that would be subject to regression analysis.

Measurements made on each plot are indicated by entries on the sample field forms (figs. 2, 3, and 4). Only values needed to carry out necessary computations are shown. Additional information can be obtained if desired, especially if local experience indicates that additional independent variables should be tested in the regression analyses.

The plot description form (fig. 2) provided spaces for recording descriptive material and the results of computations. Alternative procedures for site index determination were allowed for. Site indexes of the Black Hills plots were determined from height and age (Hornibrook 1939) where the trees were old enough and where there was no indication of reduced height growth through suppression. Elsewhere, site index was determined from soil and topography (Myers and Van Deusen 1960a). The effects of stand density could have been accounted for by applying a correction to site indexes determined from height and age (Lynch 1958).

Field measurements of living trees were those shown in the first six columns of figure 3. Each tree was given a temporary number by stapling a numbered card to it. This permitted most efficient use of small crews. The record of figure 3 was completed one column at a time, yet all data from any one tree could still be identified as such. Diameters of all trees on each plot were measured with a diameter tape. Total heights were measured

Yield Table Study -- Plot Description and Summations

Plot No. 62 (1) Species Ponderosa pine

Date 6-20-63 By CAM CPP

Location Black Hills National Forest. SW 1/4 Sec 33

T4N R5E BHM. 150 yds west of road junction.

Plot area 0.454 acres. Blow-up factor 2.203

* * * * * * * * * * *

Soil depth ____ ins. Slope ____ % Slope distance ____

Aspect ____ Dom. height 85 ft. Dom. age 125 yr.

Trial site index ____ ft. Correction ____ Site index 73 ft.

Thinned Several Stocking level 10 years ago 90

STAND SUMMARY, PER ACRE

Item	Present		Past	
Number of trees (live)	70	(3)	70	(4)
Basal area, total	106.67	(5)	93.18	(6)
Average D.B.H., inches	16.7	(7)	15.6	(8)
Average height, feet	83	(9)		(10)
Main stand age, years	125	(11)	115	(12)
Total cubic feet	3891.2	(13)		(14)
Merchantable cubic feet	3733.5	(15)		(16)
Board feet, Scribner	19,232	(17)		(18)
Board feet, Int-¼"	22,249	(19)		(20)

No evidence of past suppression.

Yield Table Study -- Description of Live Trees

Plot No. 62 Species Ponderosa pine Date 6-20-63

Sheet 1 of 2 sheets

(1) Tree No.	(2) Present D.B.H.	(3) Present Ht.	(4) Present Crown	(5) Present Age	(6) 10-yr. radial growth	(7) P.I. Diam.	(8) Past D.B.H.
1	16.6	77	C	118	.35	.8	15.8
2	21.0	86	C	119	.35	.8	20.2
3	17.8	84	D	124	.40	.9	16.9
4	16.0	74	C		.40	.9	15.1
5	15.3	79	D		.40	.9	14.4
6	18.7	84	D	115	.55	1.2	17.5
7	16.6	80	C	129	.60	1.3	15.3
8	18.2	81	D	129	.80	1.8	16.4
9	15.4	76	C		.65	1.4	14.0
10	16.5	84	D	123	.60	1.3	15.2
11	17.8	86	D		.45	1.0	16.8
12	18.8	83	D	119	.50	1.1	17.7
13	10.1	81	I		.25	.6	9.5
14	18.4	90	C		.45	1.0	17.4
15	18.1	88	D	128	.45	1.0	17.1
16	11.5	77	I		.25	.6	10.9

Yield Table Study -- Diameters of Trees Dead 0-10 Years

Plot No. 62 Species Ponderosa pine Date 6-20-63

D.B.H.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Total
0											
1											
2											
3											

NONE

Figure 2.--(Upper left)
Sample field form for plot description and summary.
Figure 3.--(Upper right)
Sample field form for record of live trees.
Figure 4.--(Lower right)
Sample field form for record of mortality.

with an Abney level and a measured base. A sample of heights was obtained where plots contained large numbers of small trees. The record of heights provided: (1) heights (6-8) for site index determination if soil-site index was not used, (2) heights for construction of a height-diameter curve, and (3) heights (about 20) to determine average height of dominant and codominant trees. Total ages were determined from borings of dominant and codominant trees at breast height (at least 10) and at the ground line (3 to 5). Ages were determined for intermediate and overtopped trees when needed to confirm that the stand was even-aged, but were not used in computations. Radial growth of the wood at breast height was determined for each tree by boring along the best estimate of average radius.

Evidence from increment cores of past crowding or stagnation and the stand age when crowding effects began and ended were described at the bottom of figure 2.

Diameters of trees that died during the previous 10 years were recorded as inside or outside bark measurements (fig. 4). Inside bark measurements were later converted to outside bark equivalents (Myers and Van Deusen 1958). Appearance of trees dead 0 to 10 years was determined by examination on permanent plots and in stands for which date of thinning was known.

A few additional items of information should be gathered or checked in the field. For example, the effects of initial thinning and rethinning on average stand diameter can be determined by trial marking of unthinned and growth-prediction plots, as described below.

Initial Computations

Field data described in the previous section were converted to volumes and other values for each plot and per acre. Basal area and other per-acre values, average stand diameter, and site index were then used as dependent and independent variables in the solution of prediction equations as explained in the descriptions of working tools. Most operations were performed on electronic computers; a few relationships were solved graphically to avoid assumptions as to curve form.

Field data from the growth-prediction plots were reduced to amounts per acre as follows:

1. A curve of height on diameter was prepared to supply missing values where the heights of all trees had not been measured (column 3 of fig. 3).
2. Present diameter outside bark was converted to past diameter outside bark by use of radial wood growth and equations that account for bark growth (Myers and Van Deusen 1958) (columns 2, 6, 7, 8 of fig. 3).
3. Past number of trees equaled present number of live trees (fig. 3) plus any mortality during the previous 10 years (fig. 4). Past and present numbers were raised to an acre basis by multiplying with the blowup factor (fig. 2).
4. Present basal area was computed with the diameters of column 2 of figure 3. Past basal area was obtained from the diameters of column 8 of figure 3 and entries in figure 4.
5. Average stand diameter was the diameter of the tree of average basal area. This definition of average diameter applied every place this variable was used or recorded as a result.
6. Cubic- and board-foot volumes were computed with volume equations of the form $V = a + b D^2 H$ (Myers 1964). They were raised to volumes per acre and recorded on figure 2.
7. Present age of the main stand was the average of the ages of dominant and codominant trees (column 5 of fig. 3). Past age equaled present age minus 10 years.
8. Average height of dominant and codominant trees was obtained from columns 3 and 4 of figure 3.
9. Site index was determined by one of the two methods decided upon initially (height and age or soil site) and recorded in figure 2.

Data from unthinned plots were summarized in a manner similar to data from growth-prediction plots. Each unthinned plot furnished the following:

1. Area and blowup factor.
2. Site index.
3. Number of trees, total and by 1-inch diameter classes. (Full-inch diameter classes were used in all computations involving

diameter classes; the 9-inch class included trees from 9.0 to 9.9.)

4. Basal area.
5. Average stand diameter.

Largest Diameter in Stand

Diameter tallies from the unthinned plots were used to estimate the largest diameter in young, unthinned, even-aged stands. Largest diameter can be plotted over average stand diameter, or the relationship between the variables can be determined by least squares. Estimated largest diameter in a stand is then determined for each stand diameter within the range of the field data:

Average stand d.b.h. (Inches)	Largest d.b.h. in stand (Inches)
2.5	4.0
2.6	4.1
2.7	4.3
2.8	4.5
2.9	4.6
3.0	4.8
3.1	4.9
3.2	5.1
3.3	5.2
3.4	5.4
3.5	5.5
3.6	5.7
3.7	5.8
3.8	6.0
3.9	6.2
4.0	6.3

Stand Tables

Tree tallies from the unthinned plots were converted to cumulative stand tables. Procedure for construction of the stand tables was as follows:

1. Numbers of trees in each 1-inch diameter class of each plot were converted to cumulative frequencies in percent (Bruce and Schumacher 1950, p. 212).
2. Cumulative frequencies were plotted over stand diameter, with a separate curve for each diameter class. The 100-percent points of the plot data were replaced by previously computed estimates of the largest diameter in a stand (tabulation above). In all cases, the new 100-percent points fell on the trend lines established by the 80- to 99-percent values of each diameter class.
3. Subdivisions of the data were compared to determine if the distribution of frequencies varied within a stand diameter class because of stand density or site quality. No such trends could be established, so all data were treated as a single sample.
4. Cumulative frequencies in percent were read from each curve and tabulated for ready reference during yield table construction (see table 3).

Periodic Diameter Increase

Values from the plot description sheets (fig. 2) were used in multiple regression analysis to obtain an equation for estimating present stand diameter from past stand diameter. Variables in the final equations were then relabeled so that past became present and present became future. The equation thus predicts stand diameter in 10 years when present diameter and other descriptive data are known.

Stand diameter of Black Hills ponderosa pine 10 years in the future can be estimated from the relationship:

$$D_F = 1.0097\, D_P + 0.0096\, S - 1.5766 \log B_P + 3.3021$$

where

D_F = stand diameter in 10 years, in inches.
D_P = present stand diameter, in inches.
S = plot site index.
B_P = present basal area per acre, in square feet.

This working tool is applicable to even-aged stands with stocking levels of 50 to 170 (table 2) at the beginning of the 10-year prediction period. Ranges of the original field data were:

D_P, 3.4 to 16.3 inches
S, 37 to 73 feet
B_P, 48 to 150 square feet.

Examination of the differences between actual and computed plot diameters indicated that some extrapolation is possible beyond the limits of the data.

Diameter Increase from Thinning

There are two types of thinning from below, each of which causes stand diameter to increase without actual tree growth. An increase in average diameter accompanies the abrupt reduction in stand density caused by initial thinning. A lesser increase occurs when a stand is rethinned to the same stocking level to which density was reduced one or more times previously.

Rethinning a Black Hills ponderosa pine stand to the same stocking level it had 10 years previously results in an increase in average stand diameter of 0.4 inch. No relationship could be found between amount of increase and stocking level (range 70 to 120) or initial diameter (range 5.0 to 17.5 inches). Actual increase in any one stand will depend on the condition and arrangement (therefore need for cutting) of the largest trees. An increase of 0.4 inch was average for conditions present on the 24 plots examined.

Effect of rethinning is most conveniently determined by simulated marking of growth-prediction plots. Plot boundaries are marked so the plots can be relocated after past basal area, diameter, and stocking level have been computed and found to be within desired limits.

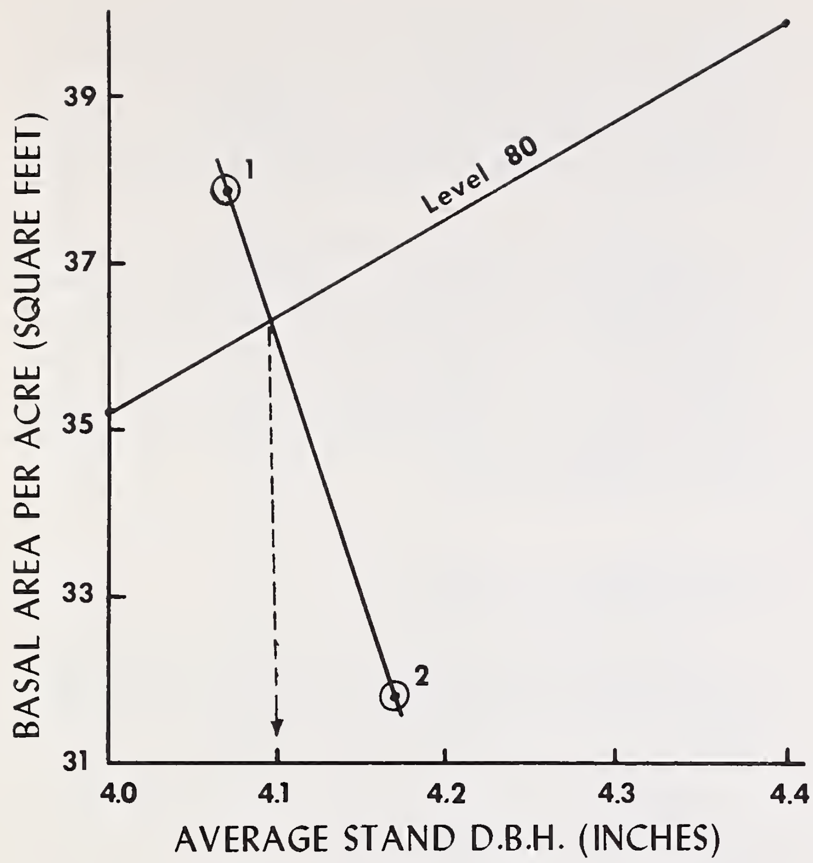
Change in stand diameter because of initial thinning can be determined by marking previously unthinned young stands. Plots established for other purposes (such as stand tables) can be used to get additional use from the field measurements and computations. Marking to all stocking levels of interest can be simulated on each plot and new average diameters determined. Data from thinning studies or administrative thinnings may be added to the sample where such cutting was to suitable stocking levels.

Because of the numerous possible combinations of initial stand density, desired stocking level, and initial stand diameter, the procedure of trial marking of sample plots was extended to provide a more convenient tool for estimation of diameter changes due to initial thinning. Most of the procedure is best carried out on electronic computers, but is described here as though done manually. Numerical examples refer to table 6 and figure 5.

1. Prepare a stand table for the stand, using the average stand diameter expected just before thinning (see "Stands Prior to Thinning") and the appropriate cumulative frequencies (table 3).
2. Assemble cards equal in number to the number of live trees before thinning (1680 in table 6) and label each card with a diameter so that the group of cards reproduces the stand table: 91 cards with "0", 240 cards with "1", and so forth.
3. Shuffle the cards so they become arranged in random order.
4. Estimate the number of trees to be retained per acre (400), and divide the number of original trees by the number of reserve trees, 1,680/400 = 4 (approx.).
5. Beginning with the first card and maintaining the original random order, divide the pile of cards into as many smaller piles as the number of reserve trees per acre. Each small pile, except perhaps the last one, will contain the number of cards determined by the quotient of the previous step.

Table 3.--Stand tables for young, unthinned Black Hills ponderosa pine. (Numbers of trees expressed as cumulative frequencies in percent.)

Upper d.b.h. limit (Inches)	Average d.b.h. of stand (Inches)															
	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
	Percent															
0.9	16.5	14.9	13.3	11.7	10.1	8.6	7.0	5.4	3.8	2.5	1.3	0.2	0	0	0	0
1.9	43.3	39.9	36.6	33.2	29.8	26.5	23.1	19.7	16.4	13.0	10.0	7.5	5.4	3.7	2.3	1.1
2.9	74.9	71.2	67.5	63.8	60.0	56.3	52.7	48.9	44.9	40.8	36.8	32.7	28.7	24.6	20.5	16.5
3.9	98.3	96.6	94.6	92.5	90.2	87.7	85.1	82.2	79.2	76.0	72.9	69.8	66.7	63.6	60.6	57.4
4.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.1	96.9	95.5	93.9	92.0	89.9	87.5	84.8
5.9								100.0	100.0	100.0	100.0	100.0	100.0	99.4	98.0	96.6
6.9														100.0	100.0	100.0



N = 1680 $\bar{D}$ = 3.2

D	CUMUL PCT	CUMUL TREES	TREES
0-0.9	5.4	91	91
1-1.9	19.7	331	240
2-2.9	48.9	822	491
3-3.9	82.2	1381	559
4-4.9	99.1	1665	284
5-5.9	100.1	1680	15

Largest = 5.1

	1:4 Point 1	1:5 Point 2
Trees	420	336
BA	37.9	31.8
Dbh	4.07	4.17

Figure 5.--Determination of average d.b.h. after thinning. Site index 40, age 30. (See table 6.)

6. Tally the value of the largest diameter in each small pile. This produces an estimate of the stand table after thinning. Steps 3 to 6 may be repeated and the two estimated stand tables averaged to produce a single estimate.
7. Multiply the number of trees in each diameter class of the stand table by the basal area of the class midpoint. Use the estimated upper limit of the largest diameter class (tabulation, p. 9) to determine its class midpoint. Total the products to obtain basal area per acre.
8. Divide basal area by number of trees, and determine the diameter (to 0.01 inch) equivalent to this average basal area.
9. Plot a portion of the appropriate column of table 2, as shown in figure 5, for stocking level 80.
10. Plot basal area (step 7) over average diameter (step 8) on the graph of step 9, as done for point 1 of figure 5.
11. Repeat steps 3 to 8 with a ratio (step 4) that will produce a point on the other side of the line of step 9, for example, 1:5. Plot basal area and average diameter of the stand table estimated by this step, as shown by point 2 of figure 5.
12. Draw a line between the two points plotted in steps 10 and 11. The point of intersection of this line with the stocking level line (step 9) is projected to the horizontal axis of the graph. The value read on this axis to 0.1 inch is expected stand diameter after thinning. Comparison of results obtained by this method with data from actual semipermanent plots indicated that the difference between actual and estimated diameters will frequently be 0.1 inch or less.

Periodic Basal Area Growth

Basal area per acre in 10 years can be estimated from the relationship:

$$B_F = 0.9263\, B_P + 0.0006\, N \times S + 15.7887$$

where

B_F = basal area per acre in 10 years, in square feet.

B_P = present basal area per acre in square feet.

N = present number of trees per acre.

S = site index in feet.

This equation may be used under the same conditions as the diameter growth equation given above.

Height of Dominants and Codominants

A record of heights attained at various ages was needed for later use in the computation of volumes. Height-age relationships were established for stands continuously free to grow in height, so that heights attainable by managed stands could be estimated. Heights attained by dominant and codominant trees were determined because they are far less affected by thinning from below than are average heights of all trees. Each site index class of interest was sampled so the effect of site quality on height growth could be determined.

Records of the growth-prediction plots (fig. 2) were sorted to identify those plots that probably had a history of normal height growth. The data were further sorted by 10-foot site index classes.

Average height of the dominant and codominant trees of each stand was plotted over stand age, with a separate set of points for each site index class. Smooth, balanced curves were drawn through each set of points, and heights at 10-year intervals were read from each curve (table 4). Where necessary, heights were adjusted to the site class midpoint by multiplying curve height by the proportion: (midpoint of site index class) ÷ (actual average site index of the data in the class).

Table 4.--Average height of dominant and codominant trees at various ages, Black Hills ponderosa pine

Main stand age (Years)	Site index class			
	40	50	60	70
	- - - - - Feet - - - - -			
10	4.5	4.5	4.5	4.5
20	9	10	12	16
30	11	16	20	26
40	17	22	28	35
50	21	28	35	43
60	26	33	41	50
70	30	38	47	56
80	34	43	52	61
90	37	47	57	66
100	40	50	60	70
110	43	53	63	74
120	45	56	66	77
130	46	59	69	80
140	48	61	71	83
150	50	63	73	86

Table 4 is very similar to table 1 of Technical Bulletin 630 (Meyer 1938). This suggests that heights from good site index curves may supplement or substitute for local data, if necessary. The site index curves must be based on the crown classes desired for yield table computations.

Stand Volume Equation

Cubic volumes per acre of Black Hills ponderosa pine can be estimated by the relationship:

$$V = 0.4047\, B \times H + 25.5970\, D - 191.6433$$

$$R = 0.999$$

$$S_{xy} = 39.648 \text{ (1.7\% of mean)}$$

where

V = gross volume per acre in cubic feet from ground line to tip of all trees more than 4.5 feet tall.

B = basal area per acre in square feet.

H = average height of dominant and codominant trees in feet.

D = average stand diameter in inches.

Data for determination of the regression constants were obtained from present volume, height, and diameter of each plot (fig. 2). Total cubic feet was used as the unit for projection because it does not vary with changes in standards of merchantability.

Volume Conversion Factors

Total cubic volumes were converted to other units of interest to the forest manager by means of conversion factors (table 5). Volumes from the plot summary records (fig. 2) were used to compute ratios that were plotted over stand diameter (Chapman and Meyer 1949, p. 384). Yields could also have been expressed as weight of dry wood if emphasis were on fiber production (Myers 1960).

Ratios were not computed for the smallest average stand diameters because the varia-

Table 5a. --Factors for conversion of stand volumes in total cubic feet to merchantable cubic feet per acre.[1]

Average stand diameter (Inches)	Ratio of merchantable to total volume	Average stand diameter (Inches)	Ratio of merchantable to total volume
5.0	0.332	11.0	0.935
5.2	.377	11.2	.936
5.4	.422	11.4	.937
5.6	.465	11.6	.938
5.8	.508	11.8	.939
6.0	.552	12.0	.940
6.2	.597	12.2	.941
6.4	.639	12.4	.942
6.6	.678	12.6	.942
6.8	.710	12.8	.943
7.0	.740	13.0	.944
7.2	.766	13.5	.947
7.4	.789	14.0	.949
7.6	.809	14.5	.951
7.8	.826	15.0	.953
		15.5	.955
8.0	.842		
8.2	.856	16.0	.956
8.4	.868	16.5	.957
8.6	.876	17.0	.958
8.8	.884	17.5	.959
		18.0	.960
9.0	.892	18.5	.961
9.2	.899		
9.4	.906	19.0	.962
9.6	.913	19.5	.963
9.8	.920	20.0	.964
		20.5	.965
10.0	.926	21.0	.966
10.2	.930	21.5	.966
10.4	.932		
10.6	.933	22.0	.967
10.8	.934		

[1] To 4.0-inch top in trees 6.0 inches d.b.h. and larger.

Table 5b. --Factors for conversion of stand volumes in total cubic feet to board feet per acre.[1]

Average stand diameter (Inches)	Ratio of board feet to total volume: Scribner	Ratio of board feet to total volume: International 1/4 inch	Average stand diameter (Inches)	Ratio of board feet to total volume: Scribner	Ratio of board feet to total volume: International 1/4 inch
11.0	1.52	1.81	14.0	4.06	4.88
11.2	1.71	2.04	14.5	4.30	5.14
11.4	1.91	2.27	15.0	4.44	5.30
11.6	2.10	2.51	15.5	4.58	5.44
11.8	2.30	2.74	16.0	4.72	5.57
			16.5	4.85	5.69
12.0	2.48	2.97	17.0	4.97	5.78
12.2	2.68	3.21	17.5	5.08	5.86
12.4	2.86	3.44			
12.6	3.04	3.66	18.0	5.17	5.93
12.8	3.21	3.86	18.5	5.26	5.99
			19.0	5.33	6.04
13.0	3.37	4.06	19.5	5.40	6.09
13.2	3.52	4.24	20.0	5.46	6.14
13.4	3.68	4.42	20.5	5.52	6.18
13.6	3.81	4.58	21.0	5.58	6.22
13.8	3.94	4.73	21.5	5.63	6.25
			22.0	5.68	6.28

[1] In trees 12.0 inches d.b.h. and larger to an 8-inch top.

bility of conversion factors increases as stand diameter decreases. Likewise, minimum diameter for sawtimber was set at 12 inches to further reduce variability among plots. Most ponderosa pines 12 inches in diameter contain at least one saw log; most 11-inch pines do not.

Absence of conversion factors for the smallest stand diameters has no effect on yield table construction. An occasional entry for merchantable cubic feet or board feet will be missing when salable material is obviously present. No information is lost because salable material will not be a part of thinnings until stand diameter is large enough for conversion factors to be reliable.

Other ways of determining salable volume, such as stand volume equations, were tested for Black Hills ponderosa pine. No method tried was as satisfactory as conversion of total cubic volume.

Derivation of Yield Tables

The working tools described above were used to derive two sets of yield tables for ponderosa pine in the Black Hills. The tables indicate potential productivity of managed stands for the site qualities and management goals selected. Site index classes 40, 50, 60, and 70 (base age 100 years) and stocking levels 80 and 100 describe the range of site quality in the Black Hills and stocking appropriate for the site quality.

The first four tables (tables 6, 7, 8, and 9) give volume and other information on the assumption that cutting interval is 10 years. These tables are useful in such computations as determination of culmination of mean annual increment. They are similar in form to normal yield tables, but apply to managed stands.

The second group of tables (tables 10, 11, 12, and 13) illustrates what growth in actual stands may be if the interval between cuts is 20 years. One more management decision, the cutting cycle, is thus introduced into the computations.

Table 6. --Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 40, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,680	94	3.2	11	310	--	--	320				
30	397	36	4.1	11	80	--	--	1,283	58	230	0	0
40	397	63	5.4	17	380	170	--					
40	298	55	5.8	17	330	170	--	99	8	50	0	0
50	298	75	6.8	21	620	440	--					
50	237	67	7.2	21	560	430	--	61	8	60	10	0
60	237	85	8.1	26	910	770	--					
60	191	75	8.5	26	820	710	--	46	10	90	60	0
70	191	90	9.3	30	1,140	1,030	--					
70	155	80	9.7	30	1,020	940	--	36	10	120	90	0
80	155	93	10.5	34	1,360	1,270	--					
80	123	80	10.9	34	1,190	1,110	--	32	13	170	160	0
90	123	92	11.7	37	1,480	1,390	3,400					
90	100	80	12.1	37	1,320	1,240	3,400	23	12	160	150	0
100	100	91	12.9	40	1,610	1,520	5,300					
100	83	80	13.3	40	1,440	1,370	5,200	17	11	170	150	100
110	83	90	14.1	43	1,740	1,650	7,100					
110	70	80	14.5	43	1,570	1,490	6,800	13	10	170	160	300
120	70	89	15.3	45	1,830	1,740	8,300					
120	60	80	15.7	45	1,670	1,590	7,700	10	9	160	150	600
130	60	89	16.5	46	1,890	1,810	9,200					
130	51	80	16.9	46	1,730	1,660	8,600	9	9	160	150	600
140	51	87	17.7	48	1,950	1,880	10,000					

Table 7. --Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 50, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,600	101	3.4	16	550	--	--	400				
30	384	39	4.3	16	170	--	--	1,216	62	380	0	0
40	384	66	5.6	22	540	260	--					
40	288	57	6.0	22	470	260	--	96	9	70	0	0
50	288	79	7.1	28	890	670	--					
50	225	69	7.5	28	780	630	--	63	10	110	40	0
60	225	89	8.5	33	1,210	1,060	--					
60	178	77	8.9	33	1,070	950	--	47	12	140	110	0
70	178	93	9.8	38	1,490	1,370	--					
70	141	80	10.2	38	1,300	1,210	--	37	13	190	160	0
80	141	95	11.1	43	1,740	1,630	3,000					
80	111	80	11.5	43	1,490	1,400	3,000	30	15	250	230	0
90	111	93	12.4	47	1,900	1,790	5,400					
90	90	80	12.8	47	1,660	1,560	5,300	21	13	240	230	100
100	90	92	13.7	50	2,020	1,920	7,800					
100	74	80	14.1	50	1,790	1,700	7,300	16	12	230	220	500
110	74	91	15.0	53	2,140	2,040	9,500					
110	62	80	15.4	53	1,920	1,830	8,700	12	11	220	210	800
120	62	90	16.3	56	2,260	2,160	10,900					
120	53	80	16.7	56	2,050	1,960	10,000	9	10	210	200	900
130	53	90	17.6	59	2,400	2,300	12,200					
130	45	80	18.0	59	2,180	2,090	11,300	8	10	220	210	900
140	45	89	19.0	61	2,480	2,390	13,200					

Table 8.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 60, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,550	110	3.6	20	790	--	--	450				
30	371	41	4.5	20	260	--	--	1,179	69	530	0	0
40	371	70	5.9	28	760	400	--					
40	274	59	6.3	28	640	400	--	97	11	120	0	0
50	274	82	7.4	35	1,160	910	--					
50	215	71	7.8	35	1,020	840	--	59	11	140	70	0
60	215	91	8.8	41	1,540	1,360	--					
60	169	78	9.2	41	1,340	1,210	--	46	13	200	150	0
70	169	96	10.2	47	1,890	1,760	--					
70	131	80	10.6	47	1,600	1,490	--	38	16	290	270	0
80	131	96	11.6	52	2,130	2,000	4,500					
80	102	80	12.0	52	1,800	1,690	4,500	29	16	330	310	0
90	102	94	13.0	57	2,310	2,180	7,800					
90	82	80	13.4	57	2,000	1,890	7,300	20	14	310	290	500
100	82	93	14.4	60	2,430	2,310	10,300					
100	67	80	14.8	60	2,130	2,030	9,300	15	13	300	280	1,000
110	67	91	15.8	63	2,540	2,430	11,900					
110	56	80	16.2	63	2,260	2,160	10,800	11	11	280	270	1,100
120	56	90	17.2	66	2,660	2,550	13,300					
120	47	80	17.6	66	2,400	2,300	12,200	9	10	260	250	1,100
130	47	89	18.6	69	2,760	2,650	14,600					
130	41	80	19.0	69	2,530	2,430	13,500	6	9	230	220	1,100
140	41	90	20.1	71	2,920	2,810	16,000					

Table 9.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 70, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,480	117	3.8	26	1,130	--	--	520				
30	458	53	4.6	26	480	--	--	1,022	64	650	0	0
40	458	87	5.9	35	1,190	630	--					
40	343	74	6.3	35	1,020	630	--	115	13	170	0	0
50	343	102	7.4	43	1,780	1,410	--					
50	268	89	7.8	43	1,560	1,290	--	75	13	220	120	0
60	268	113	8.8	50	2,320	2,050	--					
60	212	98	9.2	50	2,020	1,820	--	56	15	300	230	0
70	212	118	10.1	56	2,740	2,540	--					
70	166	100	10.5	56	2,340	2,190	--	46	18	400	350	0
80	166	118	11.4	61	3,010	2,820	5,900					
80	132	100	11.8	61	2,580	2,420	5,900	34	18	430	400	0
90	132	116	12.7	66	3,230	3,050	10,100					
90	107	100	13.1	66	2,810	2,660	9,700	25	16	420	390	400
100	107	114	14.0	70	3,410	3,230	13,800					
100	88	100	14.4	70	3,010	2,860	12,800	19	14	400	370	1,000
110	88	114	15.4	74	3,610	3,450	16,400					
110	73	100	15.8	74	3,210	3,070	15,000	15	14	400	380	1,400
120	73	112	16.8	77	3,740	3,580	18,400					
120	62	100	17.2	77	3,360	3,220	16,900	11	12	380	360	1,500
130	62	112	18.2	80	3,900	3,740	20,300					
130	53	100	18.6	80	3,520	3,380	18,600	9	12	380	360	1,700
140	53	111	19.6	83	4,040	3,890	21,900					

Table 10.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 40, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,680	94	3.2	11	310	--	--	320				
30	397	36	4.1	11	80	--	--	1,283	58	230	0	0
50	397	86	6.3	21	700	430	--					
50	257	63	6.7	21	510	360	--	140	23	190	70	0
70	257	99	8.4	30	1,220	1,060	--					
70	182	77	8.8	30	960	850	--	75	22	260	210	0
90	182	105	10.3	37	1,650	1,540	--					
90	128	80	10.7	37	1,280	1,200	--	54	25	370	340	0
110	128	104	12.2	43	1,930	1,810	5,200					
110	92	80	12.6	43	1,520	1,430	4,600	36	24	410	380	600
130	92	100	14.1	46	2,030	1,920	8,300					
130	20	29	16.4	46	770	740	3,000	72	71	1,260	1,180	5,300
140	20	35	17.9	48	950	910	4,200	20	35	950	910	4,200
Total -								2,000	258	3,670	3,090	10,100

Table 11.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 50, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,600	101	3.4	16	550	--	--	400				
30	384	39	4.3	16	170	--	--	1,216	62	380	0	0
50	384	91	6.6	28	1,010	690	--					
50	245	66	7.0	28	730	540	--	139	25	280	150	0
70	245	103	8.8	38	1,630	1,440	--					
70	169	78	9.2	38	1,250	1,120	--	76	25	380	320	0
90	169	110	10.9	47	2,170	2,030	2,900					
90	115	80	11.3	47	1,620	1,520	2,900	54	30	550	510	0
110	115	106	13.0	53	2,410	2,280	8,100					
110	82	80	13.4	53	1,870	1,770	6,900	33	26	540	510	1,200
130	82	102	15.1	59	2,630	2,510	11,800					
130	18	30	17.5	59	980	940	4,300	64	72	1,650	1,570	7,500
140	18	36	19.1	61	1,180	1,140	5,600	18	36	1,180	1,140	5,600
Total -								2,000	276	4,960	4,200	14,300

Table 12.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 60, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,550	110	3.6	20	790	--	--	450				
30	371	41	4.5	20	260	--	--	1,179	69	530	0	0
50	371	96	6.9	35	1,350	980	--					
50	233	68	7.3	35	950	740	--	138	28	400	240	0
70	233	110	9.3	47	2,140	1,930	--					
70	155	80	9.7	47	1,570	1,440	--	78	30	570	490	0
90	155	114	11.6	57	2,730	2,560	5,700					
90	102	80	12.0	57	1,960	1,840	4,900	53	34	770	720	800
110	102	107	13.9	63	2,900	2,760	11,600					
110	72	80	14.3	63	2,210	2,100	9,300	30	27	690	660	2,300
130	72	103	16.2	69	3,100	2,970	14,800					
130	16	30	18.6	69	1,130	1,080	5,200	56	73	1,970	1,890	9,600
140	16	36	20.3	71	1,360	1,310	6,800	16	36	1,360	1,310	6,800
Total -								2,000	297	6,290	5,310	19,500

Table 13.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 70, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchant-able volume	Sawtimber volume	Trees	Basal area	Total volume	Merchant-able volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,480	117	3.8	26	1,130	--	--	520				
30	458	53	4.6	26	480	--	--	1,022	64	650	0	0
50	458	119	6.9	43	2,050	1,490	--					
50	291	85	7.3	43	1,470	1,140	--	167	34	580	350	0
70	291	131	9.1	56	3,020	2,700	--					
70	201	99	9.5	56	2,290	2,080	--	90	32	730	620	0
90	201	138	11.2	66	3,770	3,530	6,400					
90	136	100	11.6	66	2,780	2,600	5,800	65	38	990	930	600
110	136	131	13.3	74	4,080	3,860	14,700					
110	98	100	13.7	74	3,150	2,990	12,200	38	31	930	870	2,500
130	98	130	15.6	80	4,420	4,220	20,400					
130	17	31	18.2	80	1,270	1,220	5,900	81	99	3,150	3,000	14,500
140	17	37	20.0	83	1,570	1,510	7,900	17	37	1,570	1,510	7,900
Total -								2,000	335	8,600	7,280	25,500

Steps in the derivation of yield tables with 10-year cutting intervals were as follows:

1. Forms with the headings shown in tables 6 to 13 were prepared for each combination of site index and growing stock level of interest. Two values were entered for each age, beginning with age at initial thinning. The first age of each pair identified conditions just prior to thinning; the second age identified conditions immediately after thinning.
2. Diameters, basal areas, and numbers of trees were recorded for stands prior to thinning at age 30. Number of trees and stand diameter were chosen as the starting point of projections, as described in the section "Initial Management Decisions." Basal area before thinning was the product of number of trees times the basal area corresponding to stand diameter.
3. Average heights of dominant and codominant trees (table 4) were recorded in the appropriate spaces in the fifth column of each yield table. Both heights at any age were considered to be equal, because thinning from below was expected to have minor effect on average dominant and codominant height.
4. Stand diameter after initial thinning to the prescribed growing stock level was determined by procedures described in the "Computations" section.
5. Basal area corresponding to stand diameter after thinning was obtained from table 2 in the column headed by the appropriate stocking level designation. Portions of the appropriate column of table 2 were graphed where table interpolation was to be avoided.
6. Number of trees after thinning at age 30 was computed by dividing basal area per acre from table 2 by the basal area equivalent to the stand diameter.
7. Stand diameter was projected from after thinning at age 30 to before thinning at age 40 by means of the diameter growth equation. Projections could have been made with either the diameter growth equation or the basal area equation. Diameter projections were used because most steps in procedure used diameter as an important independent variable, and the diameter equation appeared to be better than the basal area equation. Mathematical relationships between numbers of trees, basal area, and average diameter will not correspond exactly if both equations are used together. Both equations are subject to error, and diameter, basal area, and number of trees would balance only by chance.
8. Number of trees before thinning at age 40 was considered to be the same as the number after thinning at age 30. Examination of numerous stands and semipermanent plots in the Black Hills indicated that noncatastrophic mortality is slight or absent in the stands of rather low density expected under management. This was especially true where the stands were of relatively low density before thinning, and spindly, undesirable trees were not so numerous as to form part of the residual stand. Losses from fire, insect epidemic, and so forth, are best handled as reductions from yield table values.
9. Basal area before thinning at age 40 was computed by multiplying number of trees by the basal area corresponding to stand diameter.
10. Stand diameter after thinning at age 40 was obtained by adding 0.4 inch to diameter before thinning, as described in "Diameter Increase from Thinning."
11. Basal area after thinning at age 40 was obtained from table 2 for the diameter computed in step 10 and for the appropriate stocking level.
12. Number of trees after thinning at age 40 was computed by dividing basal area per acre by the basal area equivalent to the stand diameter.
13. Steps 8 to 13 were repeated until the desired maximum stand age was reached, in this case 140 years. Once stand diameter reached 10.0 inches, basal area after thinning was always equal to the growing stock level for which the yield table was made (80 and 100 in the examples).
14. The basal area growth equation was used to be sure that each periodic change in basal area shown in the yield tables was reasonable. All differences between basal areas from diameter projection and from the growth equations were less than the standard error of the basal area growth equation, 4.3 square feet.
15. The stand volume equation was used to compute total cubic feet per acre before and after thinning.

16. Total cubic volumes were converted to merchantable cubic feet and to board feet Scribner Rule by means of the appropriate conversion factors (table 5).
17. Basal areas and volumes were rounded off to remove unnecessary decimals and units that had been retained during computations and checking.
18. Amounts of periodic cut and mortality were obtained for ages after initial thinning. At any given age, values after thinning were subtracted from corresponding values before thinning. No attempt was made to estimate the volume and basal area of trees that died before initial thinning. Stand density will not be definite and predictable until control is imposed by thinning.

Yield tables for cutting intervals of 20 years (tables 10-13) were derived with almost the same procedures described above. Differences in procedure were as follows:

1. Stand diameter was projected from age 30 to age 40, as above. Stand conditions at age 40 were then used to determine stand diameter at age 50, with no changes due to thinning at age 40. Other periods were handled in a similar manner.
2. Regeneration by two-cut shelterwood was shown at the end of the rotation. Length of the period between seed cut and final cut was set at 10 years. Necessary length of this period has not yet been established for the Black Hills, and this computation is intended only as an example of yield table construction. Board-foot volumes were reduced about 700 board feet per acre to compensate for the extreme truncation of diameter distributions produced by shelterwood cutting.

Projections for 20 years could have been obtained from an equation based on 20 years' growth. Tests indicated that results from two projections by the 10-year equation were equally good as one projection by a 20-year equation.

Ratios of basal area, and other adjustments such as used to obtain approximations of growth from normal yield tables, are unnecessary with the procedure described here. Actual stand conditions are used as the beginning point of projections, even if they depart from the "standards" shown in tables 6 to 13. The only requirement is that the stand values be within the limits of the data used to establish the growth equations and other relationships.

Comparison with Other Results

Most results presented here cannot be compared with the response of trees on permanent plots in the Black Hills. Records of changes in 10 years are not available for plots cut to density levels near possible management goals. Plots cut to desirable levels but remeasured at longer intervals than 10 years show good agreement between actual and computed values, if the necessary interpolations are accepted as correct. A few sawtimber stands that appear to have never suffered reduced growth because of high density exist in the Black Hills. Present average diameter, volume, and age of these stands indicate that the estimates shown in the yield tables are reasonable.

In the absence of local growth comparisons from permanent plots, 32 sets of data were obtained from permanent plots in even-aged ponderosa pine in Arizona, Washington, Oregon, Montana, and Idaho.[3] The discussion that follows is based on these data.

Repeated projections by growth equations could lead to unsatisfactory results if the changes indicated by the equations were biased. The diameter growth equation was checked for bias by the use of permanent-plot data. This comparison also provides an indication of the relative value of data from temporary and permanent plots. Differences between actual and computed future diameters, and the percentage of plots with each difference, were as follows:

[3] *Cooperation of personnel of the Intermountain and Pacific Northwest Forest and Range Experiment Stations, U. S. Forest Service, in supplying data from their areas is gratefully acknowledged.*

Actual minus estimated	Distribution of plots Temporary	Permanent
(Inches)	(Percent)	
-0.3	7	3
-.2	9	12
-.1	19	19
0	28	22
+.1	20	25
+.2	10	16
+.3	7	3

Differences were equal in range and similar in distribution for the two types of plot. Symmetry of the residuals from the temporary plots was expected because these plots supplied the data for the least-squares solution of the growth equation.

Temporary and permanent plots provided growth and yield data similar in numerical values and in degree of variability. There is no reason to deny forest managers the guidance of yield information until such time as permanent plots have been installed, measured, and analyzed.

Literature Cited

Bruce, Donald,and Schumacher, Francis X.
1950. Forest mensuration, Ed. 3, 483 pp., illus. New York: McGraw-Hill Pub. Co.

Chapman, Herman H., and Meyer, Walter H.
1949. Forest mensuration. 522 pp., illus. New York: McGraw-Hill Pub. Co.

Grosenbaugh, L. R.
1952. Plotless timber estimates—new, fast, easy. J. Forest. 50: 32-37.

Hornibrook, E. M.
1939. Preliminary yield tables for selectively cut stands of ponderosa pine in the Black Hills. J. Forest. 37: 807-812, illus.

Lynch, Donald W.
1958. Effects of stocking on site measurement and yield of second-growth ponderosa pine in the Inland Empire.* U.S. Forest Serv., Intermountain Forest and Range Exp. Sta. Res. Paper 56. 36 pp.

Meyer, Walter H.
1938. Yield of even-aged stands of ponderosa pine. U.S. Dep. Agr. Tech. Bull. 630, 60 pp., illus.

Myers, Clifford A.
1958. Thinning improves development of young stands of ponderosa pine in the Black Hills. J. Forest. 56: 656-659, illus.

________ 1960. Estimating oven-dry weight of pulpwood in standing ponderosa pines. J. Forest. 58: 889-891, illus.

________ 1964. Volume tables and point-sampling factors for ponderosa pine in the Black Hills.* U.S. Forest Serv. Res. Paper RM-8, 16 pp. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

________ and Van Deusen, James L.
1958. Estimating past diameters of ponderosa pines in the Black Hills.* U.S. Forest Serv., Rocky Mountain Forest and Range Exp. Sta. Res. Note 32, 2 pp.

________ and Van Deusen, James L.
1960a. Site index of ponderosa pine in the Black Hills from soil and topography. J. Forest. 58: 548-551, 554-555, illus.

________ and Van Deusen, James L.
1960b. Natural thinning of ponderosa pine in the Black Hills. J. Forest. 58: 962-964, illus.

________ and Van Deusen, James L.
1961. Growth of immature stands of ponderosa pine in the Black Hills.* U.S. Forest Serv., Rocky Mountain Forest and Range Exp. Sta., Sta. Paper 61, 14 pp.

*Address requests for copies to the originating office.

Myers, Clifford A.
1966. Yield tables for managed stands with special reference to the Black Hills. U. S. Forest Serv. Res. Paper RM-21, 20 pp., illus.

Presents procedures for deriving yield tables for managed stands from data obtained on temporary plots. Yield tables for Black Hills ponderosa pine are given as examples of procedure.

Myers, Clifford A.
1966. Yield tables for managed stands with special reference to the Black Hills. U. S. Forest Serv. Res. Paper RM-21, 20 pp., illus.

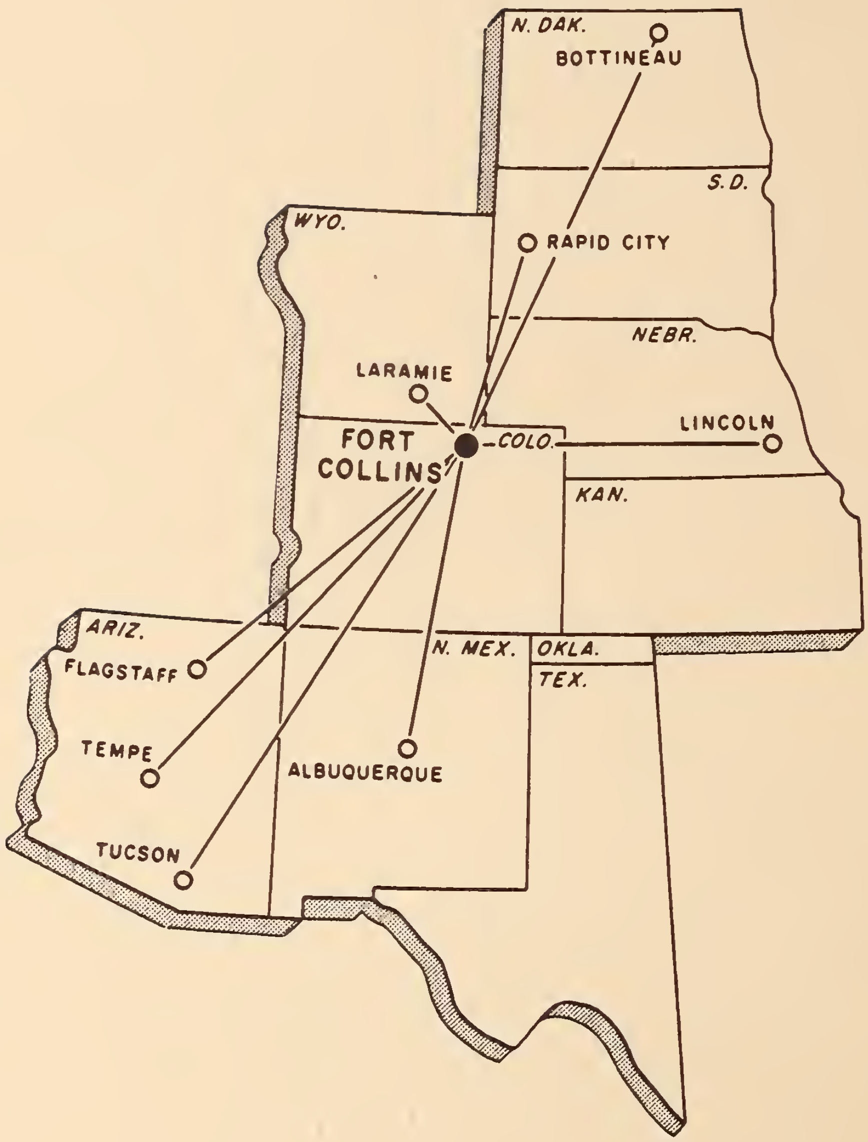
Presents procedures for deriving yield tables for managed stands from data obtained on temporary plots. Yield tables for Black Hills ponderosa pine are given as examples of procedure.

Myers, Clifford A.
1966. Yield tables for managed stands with special reference to the Black Hills. U. S. Forest Serv. Res. Paper RM-21, 20 pp., illus.

Presents procedures for deriving yield tables for managed stands from data obtained on temporary plots. Yield tables for Black Hills ponderosa pine are given as examples of procedure.

Myers, Clifford A.
1966. Yield tables for managed stands with special reference to the Black Hills. U. S. Forest Serv. Res. Paper RM-21, 20 pp., illus.

Presents procedures for deriving yield tables for managed stands from data obtained on temporary plots. Yield tables for Black Hills ponderosa pine are given as examples of procedure.


N. DAK.
BOTTINEAU
S.D.
WYO.
RAPID CITY
NEBR.
LARAMIE
FORT COLLINS
COLO.
LINCOLN
KAN.
ARIZ.
N. MEX.
OKLA.
TEX.
FLAGSTAFF
TEMPE
ALBUQUERQUE
TUCSON